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A Determination of the Melting Points of Tantalum and Tungsten

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A DETERMINATION OF THE MELTING-POINTS OF TANTALUM AND TUNGSTEN

By WILLIAM E. FORSYTHE

INTRODUCTION

In measuring temperatures much above 1550° C., the limit so far attained with the constant-volume nitrogen thermometer, the best available method is to determine the temperature in terms of the radiation from a standard source. The standard source that is taken is Kirchhoff's "black body," and the best way of expressing the temperature, at least tentatively, is in terms of a temperature-scale based on either the Stefan-Boltzmann or Wien law of radiation. The usual form of the Stefan-Boltzmann law is

$$E=A\ (T_1T_1^4-T_2T_2^4),$$

where E is the total radiation sent out from the radiator at temperature T_1, to the receiver at temperature T_2, A being a constant. The use of this law requires a measurement of the total radiation falling upon the receiver.

Wien's equation is

$$E\ =c_1\cdot\lambda^{-5}\cdot e^{\frac{-c_2}{\lambda T}},$$

where E_λ is the energy sent out from the radiator corresponding to the wave-length λ and the temperature T, c_1 and c_2 being constants. The use of this equation requires a measurement of the energy corresponding to a particular wave-length.

The temperature-scales as defined by these two relations agree with the nitrogen thermometer up to 1550° C. and have been shown by Lummer and Pringsheim[1] to agree with each other up to about 2000° C. and by Gillett[2] to be in approximate agreement up to about 2500° C.

The temperature of a non-black radiator obtained by measuring the energy corresponding to a particular wave-length is called the

[1] *Verhandlungen der deutschen physikalischen Gesellschaft*, **13**, 36, 1911.

[2] *Journal of Physical Chemistry*, **15**, 213, 1911.

"black-body" temperature and may be defined as the temperature at which a black body would send out the same amount of radiation of this wave-length. The black-body temperature of any substance will depend upon the condition of the surface, the departure from the true temperature being greater the higher the reflecting power. Since the black-body temperature in general depends upon the wave-length considered, in giving this temperature the wave-length should be specified.

Thus, to determine the true temperature of the melting-point of a metal with an optical pyrometer, either the metal may be melted in a black-body furnace and the temperature taken by observations of the furnace through a small opening, or the black-body temperature of the melting-point may be found by taking observations upon the melting metal with the optical pyrometer, and the difference between the black-body and the true temperature determined by some other means.

The present work gives the results of the direct measurement of the melting-point of tungsten in a black-body furnace and of tantalum and tungsten by a filament method, together with measurements of the black-body melting-point of both tantalum and tungsten by several methods. These black-body melting-points have been reduced to true melting-points by a method to be described later.

ERRORS

An error may be introduced in measuring the temperature of a black-body furnace due to the furnace not being in condition to give black-body radiation, which would make all temperatures as measured from it too low. The furnace will not give out black-body radiation if its walls are not uniformly heated or if there are too many or too large openings in the walls. A simple qualitative test of blackness is given by the degree of invisibility of objects of different radiating powers placed within the furnace. The condition of blackness of the furnace should be further tested by observations at some known temperature.

A second source of error may be introduced by faulty calibration of the pyrometer. This may be due to an error of setting the comparison lamp for a balance with the standard black-body

furnace; but if several readings are taken, and care is exercised always to use the same part of the filament of the comparison lamp,

TABLE I

COMPARISON OF PYROMETERS

Source	Spectral	With Glass
Small furnace	1062° C.	1062° C.
Small furnace	1218	1218
Small furnace	1386	1387
Nernst glower	1861	1858
Nernst glower	1995	2000
Nernst glower	2080	2078
Nernst glower	2080	2085
Nernst glower	2174	2172
Graphite tube furnace	1990	1990
Graphite tube furnace	2370	2380
Graphite tube furnace	2480	2490

this error may be very much reduced. Also the temperature of the standard black body used in calibrating the pyrometer may not be known accurately—an error of one degree at 1500° C. leading to an error of 3° C. at 3000° C.

In measuring temperature with an optical pyrometer an error may be introduced in determining the wave-length used with the colored glass, as the position of the maximum effective transmission of the glass may depend upon the temperature of the source, that is, on the distribution of energy in the source. To overcome this difficulty Professor Mendenhall[1] designed a direct-vision prism spectroscopic pyrometer by means of which observations can be made with light having a spectral range of not more than 25 Ångström units. Setting this pyrometer for $\lambda = 0.658\ \mu$, which was the wave-length corresponding to the position of the maximum transmission of the colored glass used on the other pyrometer, the spectral pyrometer was calibrated and the two pyrometers compared. In Table I are compared the results for the different temperatures and different sources taken with the spectroscopic and regular pyrometer, which show that within the limits of setting the two agree.

In any determination of a melting-point an error is always liable to be introduced due to an uncertainty as to the exact time of

[1] *Physical Review*, **33**, 74, 1911.

melting; furthermore, some chemical reaction may take place in the furnace between the metal and some gas or vapor that may be present, thus raising or lowering the melting-point. The method taken to guard against the above errors will be pointed out farther on.

In comparing high-temperature measurements there is much confusion due to the use of three different values for the melting-point of platinum. In Germany two temperature-scales are in use, the one giving the melting-point of platinum as 1788° C., the other placing this temperature at 1745° C. In this country most of the work is referred to the melting-point of palladium at about 1549° C. and that of platinum at about 1755° C., and in this paper we shall accept these, which are the values of Day and Sosman.[1] The constant c_2 of Wien's equation will be taken as 14,500, while the wave-length used with the optical pyrometer was 0.658 μ.

PREVIOUS DETERMINATIONS

In recent years there have been several determinations of the melting-points of tantalum and tungsten by indirect methods requiring extrapolation of several hundred degrees to reach the true melting-point. The first attempt to measure these high temperatures was in 1906 by Waidner and Burgess,[2] who found a value for the black-body melting-point of tantalum and tungsten by obtaining an equation between the current and the black-body temperature of a filament in a commercial lamp and then noting the current required to melt the filament. As this equation was obtained from measurements made below 1900° C., an extrapolation of about 1000° C. was required to reach their values for the black-body melting-point. To obtain the true temperature they assumed for tantalum and tungsten a relation between the black-body temperature observed with red light and the black-body temperature observed with blue light, a relation which had been found to hold very well for platinum. Their final value was 3080° C. for the melting-point of tungsten, and 2910° C. for the melting-point of tantalum. The method they used to obtain the relation of the

[1] *American Journal of Science* (4), **29**, 93, 1910.

[2] *Journal de Physique* (4), **6**, 830, 1910.

black-body temperature to the true temperature may give rise to a considerable error, and moreover von Wartenberg[1] has shown by direct observation that the black-body melting-point of unpolished tungsten is about 100° C. lower than the value they obtained.

In 1910 von Pirani[2] found for both tantalum and tungsten a relation between the true temperature and the black-body temperature by measuring the true temperature with a thermocouple between twisted filaments of the metal, and the black-body temperature with a Wanner pyrometer sighted at these twisted filaments. Whether the thermocouple would give the true temperature, or a temperature higher or lower than that of the surface, would depend upon how closely the wires were twisted together, while without doubt the black-body temperature as measured would be too high, due to the fact that the openings between the twisted filaments would more or less approach a black body in their radiation. These measurements on the true temperature and the black-body temperature were made below 1700° C., and to extrapolate to the melting-point it was assumed that the energy used in the filament varied as the mth power of the absolute temperature, that is:

$$E=e\cdot i=AT^m, \text{ or}$$
$$\log ei=A^1+m\cdot\log T,$$

where e is the applied voltage and i the current through the filament. This equation, which is linear in $\log ei$ and $\log T$ was found to hold over a small range of temperature, about 500° C., and was then assumed to hold up to the melting-point, which was 1300° higher. After applying a correction, Pirani's final result was 3250° C. for tungsten and 3000° C. for tantalum, using the scale giving the melting-point of platinum as 1745° C. This correction, of about 200°, added to the results as obtained by extrapolation, was due for the most part to two causes: the first being the conclusion that his temperatures as measured around 1600° C. were too low and the second the fact that in the equation $\log ei=A^1+m\cdot\log T$, m cannot remain constant but must decrease with increasing temperature. A similar extrapolation gave for Waidner and Burgess (*loc. cit.*) a result for the black-body temperature of the

[1] *Berichte der deutschen chemischen Gesellschaft*, **40**, 3287, 1907.

[2] *Verhandlungen der deutschen physikalischen Gesellschaft*, **12**, 301, 1910.

melting-point that seems to be about 100° too high, so that a like error may be introduced here. As Pirani gives no values for the black-body melting-point, a direct comparison cannot be made.

Later,[1] with somewhat similar extrapolations, Pirani found the black-body melting-point of tantalum and also measured this melting-point with a pyrometer. From this black-body melting-point and the reflecting power of tantalum the true melting-point was found by the same method as that used by von Wartenberg, which is described below. This result seems to be free from some of the objections stated above, as no corrections due to errors in the method were made.

Wartenberg (*loc. cit.*) in 1910 obtained the black-body melting-point of tungsten by melting this metal in a vacuum tube, in which a small piece of tungsten was mounted as an anode; the discharge from a Wehnelt cathode sent down upon it raised the temperature to the melting-point. Later he[2] measured the reflecting power of tungsten and was thus able to apply the equation used by Holborn and Henning to compute the true temperature. This equation, derived directly from Wien's radiation equation, is

$$1/S-1/T=c_2/\lambda \cdot \log A/\log e,$$

where T is the true temperature, S the black-body temperature, c_2 the constant of Wien's equation, λ the wave-length used, A the absorbing power, that is $(1-R)$, where R is the reflecting power. Wartenberg tested this relation for several different metals and found that it held within his limits of error up to about 2400° C. By applying this equation to his values for the black-body melting-point of tungsten he obtained about 2930° C. for the true melting-point.

The only attempt to measure the melting-point of tungsten and tantalum by a direct method was by Ruff[3] in 1910, using a vacuum furnace with a heater tube of carbon. In this furnace the heater tube had in it longitudinal slots that served the double purpose of allowing observations to be made upon the temperature inside and

[1] *Verhandlungen der deutschen physikalischen Gesellschaft*, **13**, 540, 1911.

[2] *Ibid.*, **12**, 105, 1910.

[3] *Berichte der deutschen chemischen Gesellschaft*, **43**, 1564, 1910.

also of increasing the resistance. The metals studied were placed in the furnace in the form of Seger cones and the temperature taken when the cones toppled over. Ruff obtained for the melting-point of tungsten by this method about 2650° C. The work of Wartenberg (*loc. cit.*) indicates that this is far too low, as it is 100° C. lower than the black-body melting-point.

DIRECT DETERMINATION

The vacuum furnace used in this work was designed in this laboratory by Mr. Steve and Mr. Barnes along the same general lines as the furnace of Arsem[1] of the General Electric Company and that of King[2] of the Mount Wilson Solar Observatory.

In this furnace, as shown in Fig. 1, the terminals, heater tube, etc., were all inclosed in an air-tight, water-cooled jacket made of iron pipe. The jacket was mounted vertically, with all the working parts of the furnace fastened to the top plate so that they could be easily removed. In order to be able to observe the inside of the furnace there was a window in each end 6 cm in diameter covered with plate glass 0.7 cm thick, held in place between two rubber gaskets. The terminals consisted of copper tubes 1.3 cm in external diameter and 1 cm in internal diameter, each terminal being made of two of these tubes, for inflow and outflow of cooling-water, which were connected at the bottom with a hollow brass casting, to which was fastened the graphite clamps for holding the heater tube. The graphite clamp just fitted the ends of the heater tubes of Acheson graphite which were obtained from the Acheson Graphite Company, turned to the size and shape desired. The heater tubes were 30 cm long, 1.4 cm in internal diameter, and 1.9 cm in external diameter, excepting about 2.5 cm at each end which were 2.5 cm in diameter. This made the thickness of the hot part of the tube wall about 0.3 cm. No allowance was made for the expansion of the heater tube other than slipping in the graphite clamps. To insulate the heater tube from losses of heat to the sides of the jacket it was surrounded by two carbon tubes, as shown in the figure, it being found that when the inner insulating tube was removed the

[1] *Transactions of American Electrochemical Society*, **9**, 153, 1906.

[2] *Astrophysical Journal*, **28**, 300, 1908.

maximum temperature obtainable with a given applied voltage was about 400° C. lower than when it was in place.

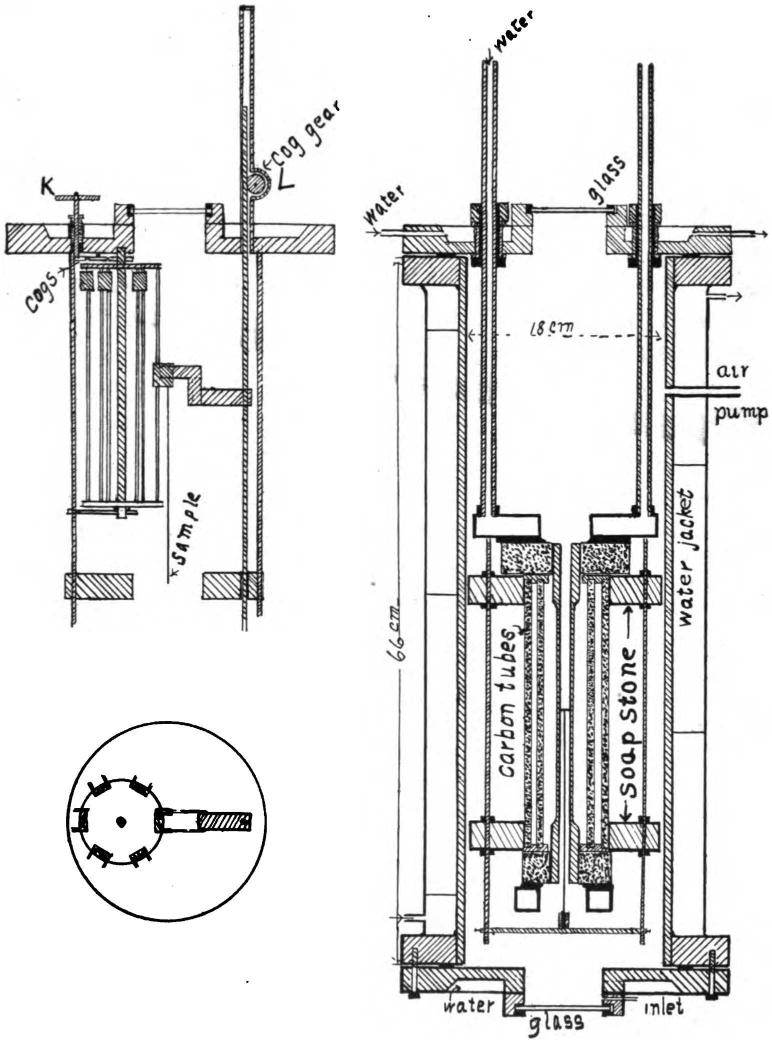

Fig. 1

The heating current was taken from a transformer, the current through the primary being regulated by two electrolytic rheostats of copper sulphate solution in earthenware tanks. These two

rheostats were connected in parallel so that a small variation of current could be obtained and the temperature easily controlled. Most of the high-temperature work was done with the transformer set so as to give 30 volts from the secondary, and with this arrangement and all the primary resistance in, the primary would draw about 150 amperes, which gave about 550 amperes through the heater tube. Table II gives the current through the heater tube, the voltage across the copper leads, and the resulting temperature of the furnace. If the temperature of the furnace was not raised above 2950° C. a heater tube would stand two or three runs; if raised much higher would stand but one run, and at a temperature higher than 3000° C. the tube would last but a few minutes.[1]

To obtain the vacuum in the furnace an electrically driven Fluess air-pump was used giving a vacuum of a few tenths of a millimeter pressure, which we were able to hold in the furnace for several days. However, when the furnace was run at the high temperatures, the pressure was hardly ever less than a few millimeters.

TABLE II

Current through Heater Tube	Voltage across Copper Leads	Temperature of Furnace
550 amperes	10 volts	1500° C.
790	13	1780
1000	16	2110
1100	18.3	2425
1175	20	2650
1240	21.5	2900
1400	25	3100

A disk of graphite about 0.1 cm thick was placed inside the heater tube somewhat nearer the lower end of the tube and held in place by a graphite rod 0.6 cm in diameter at the lower end and 0.2 cm in diameter at the top, this rod being insulated from the remainder of the furnace to prevent the formation of an arc at the center of the heater tube.

That the necessary conditions for black-body radiation were satisfied was shown by a careful determination of the melting-point of platinum with a calibrated optical pyrometer. The results

[1] Watts and Mendenhall, *Physical Review*, **33**, 65, 1911.

indicated a very satisfactory condition of blackness, since the value obtained for the melting-point agreed well with the best accepted values. Again, after the furnace had been run on steady current for a few minutes no difference could be detected between the temperature of the disk and the walls of the heater tube; furthermore, small pieces of magnesium oxide, small pieces of tungsten filaments, and a tungsten cone could not be seen when in the furnace unless they projected over an opening between the disk and the walls of the heater tube.

The specimens to be melted were carried by an arrangement shown in Fig. 1, the specimens being in the form of hairpin filaments 0.014 mm in diameter, the free ends being fastened to the two arms of the carriage. When a specimen was wanted in the furnace it was turned in place by the handle *K* and then pushed down in the furnace by the handle *L*. The specimen *s* completed an electric circuit so connected to a relay that a bell would ring when the specimens melted and broke the circuit.

The temperature of the heater tube was measured with an optical pyrometer sighted through the plate-glass window on the disk in the heater tube. This made necessary a correction for the light absorbed and reflected by the plate glass which was easily determined by measuring first the temperature of some steady source with the pyrometer and then the apparent temperature of the same source when sighted through the plate glass. For the first case, from Wien's equation,

$$E_1 = c_1 \cdot \lambda^{-5} \cdot e^{\frac{-c_2}{\lambda T_1}},$$

where E_2 is the energy corresponding to the black-body temperature T_1. For the second case, through the plate glass,

$$E_2 = c_1 \cdot \lambda^{-5} \cdot e^{\frac{-c_2}{\lambda T_2}},$$

where E_1 is the amount of light passing through the plate glass from the source at the black-body temperature T_1, T_2 being the (apparent) black-body temperature corresponding to E_2. Taking the logarithms of these two equations and substracting the first from the second,

$$\log\,[E_2/E_1] = \log K = c\,(1/T_2 - 1/T_1),$$

where K is the fractional part of the light let through by the plate glass and $c = c_2/\lambda(-\log e)$. This equation is linear in $1/T_1$ and $1/T_2$, the graph of $1/T_1$ as a function of $1/T_2$ making an angle of 45° with the axis. Thus a measurement of T_1 and T_2 at but one temperature would give the correction at all temperatures. In practice, however, T_1 and T_2 were measured for several temperatures, using as a source a Nernst glower mounted in a hollow, talc holder. As the glass would get a little fogged at times this correction was determined after each run. For clean glass this correction amounted to about 30° C. at 1600° C. and to about 70° C. at 2800° C.

In measuring the high temperatures use was made of an optical pyrometer of the Holborn-Kurlbaum type.[1] The comparison lamps were 6-volt, 1.3-ampere carbon lamps with pear-shaped bulbs about 2.5 cm in diameter, the horseshoe filament being so mounted that the top of the filament came in the center of the bulb. These lamps were aged for 24 hours on 1.35 amperes before being calibrated. In calibrating these lamps we used the sector method and as the known temperature the melting-point of palladium, this fixed point being determined directly by noting the temperature of melting Kahlbaum palladium. The melting-point of palladium was chosen as the standard temperature because it is about the highest temperature which can be directly observed with a carbon lamp in the pyrometer.

A 1/60 sector was used in the work with platinum, and a 1/180 in the work with tungsten. Starting with 1549° C. (palladium point), the range of the pyrometer with the 1/60 sector was up to 2482° C., with the 1/180 up to 2919° C. The 1/180 sector was 26.8 cm in diameter, which made the opening about 1.7 mm wide at the narrowest point. To determine whether there was an error due to diffraction with this small slit, a sector having ten openings the size of these was made up and points found on the calibration-curve for this sector. No difference was detected in using a sector made up of ten openings and one made with one large opening having the same total area.

Several times the same lamp was calibrated from the gold point

[1] Mendenhall, *Physical Review*, **33**, 74, 1911.

(1063° C.) and from the palladium point, which gave a chance to compare the palladium point with the gold point. As an average of several determinations of the palladium point by extrapolation from the gold point we obtained 1548° C., while an extrapolation down from the palladium point gave 1063° C. for the gold point.

As a test of the furnace and the pyrometer a determination of the melting-point of platinum was made. As it was known that platinum would react with carbon vapor at high temperatures, the platinum was inclosed in small magnesium tubes. The platinum gave, when it broke, all evidence of fusion, the ends being globular and small bright masses of platinum being scattered all along the lower end of the tube. Table III gives the results for the work on platinum in the graphite tube furnace. For the work in the furnace Baker platinum was used and the melting-point of this compared with that of Heraeus by the method of Mendenhall and Ingersoll.[1] The two specimens were melted on a Nernst glower and from their values for the constants of the glower the difference in temperature was calculated. As an average of ten melts the melting-point of Heraeus platinum was found to be six degrees higher than that of the Baker platinum. This gives a final average of 1755° C. for the melting-point of Heraeus platinum, which is in good agreement with the value of 1755° as set by Day and Sosman (*loc. cit.*).

TABLE III

MELTING-POINT OF PLATINUM

1909/12/2	1749° C.
	1744
	1744
	1746
	1744
1910/2/12	1756
	1751
	1749
	1756
Mean	1749° C.

The melting-point of tungsten has been measured in the vacuum furnace described above, indications of a melt being obtained by three different methods. The first was, as outlined above, the use of

[1] *Physical Review*, **25**, 1, 1907.

hairpin filaments, a melt being indicated by the bell ringing when the circuit was broken. The pieces that we were able to get out of the furnace showed every indication of fusion, the ends being tipped with small round bits of the metal. The second method was to bore a small hole in the disk in the center of the heater tube and to lay over this hole a small piece of filament which could be observed to melt and disappear as the temperature was raised. This was undertaken to find out whether direct contact of the tungsten with the carbon made any difference. The results show that the difference, if any, is slight. The third method was to press powdered tungsten into the form of a Seger cone and place this in the heater tube in such a manner that the tip of the cone would project over an opening between the disk and the walls of the tube. The results are given in Table IV.

TABLE IV

Melting-Point of Tungsten in Furnace

1911/2/18, Filament	2948° C.
3/1, Filament	2972
3/6, Filament	3010
	3000
3/7, Filament	2948
3/15, Filament	2984
	3000
	3000
3/28, Filament	2917
3/28, Filament on disk	3000
	3000
	2947
3/28, Cone	2937
Mean	2974° C.

Melting-Point as Observed in a Tungsten Wedge

8/28	2970° C.

Several attempts were made to melt tantalum in the graphite furnace but with no success. The tantalum was put in the furnace and the temperature run up to between 3000° C. and 3100° C., but when it was taken out it showed no signs of fusion. From the results given below, the melting-point cannot be as high as this. When the tantalum had been in the furnace at this high temperature it did not look at all as it did when put in; indeed, it had more the

appearance of a cinder when broken and observed with a microscope. It would seem that some compound with the carbon vapor was formed which had a higher melting-point than the tantalum.

INDIRECT METHOD

A method of obtaining the relation between the true temperature and the black-body temperature has been described by Professor Mendenhall,[1] tested for platinum, and found to give results that agree very closely with the theoretical and experimental results for this relation. This method consists of making a hollow wedge of a thin sheet of the metal and determining the black-body temperature by observing on the outside of the wedge and the true temperature inside of the wedge.

Such a curve giving the relation between black-body and true temperature for tungsten has been determined by Professor Mendenhall and the writer, while Mr. McCauley assisted with the curve for tantalum. These curves were determined with the metals in the lamp described below. The curve for tantalum was run up to the melting-point and observations made on both the true temperature and the black-body temperature, while the tungsten was run up to a black-body temperature of 2500° C., which corresponds to a true temperature of about 2700° C.

The black-body melting-point of tungsten was found by two methods. In the first place it was determined in a manner similar to that used by Waidner and Burgess,[2] excepting that in this case the lamp filaments were balanced photometrically against the heater tube of the furnace and the temperature taken with the optical pyrometer. Several lamps were worked with, but unfortunately only one lamp melted at the point under observation. This method required a correction for the lens used to project the image of the furnace on the lamp filament and also for the walls of the lamp bulb. This latter correction was determined after the melt in order to correct for any blackening of the bulbs. The ends of the filaments gave indications of a true fusion, being tipped with shiny beads of the metal.

[1] *Astrophysical Journal*, **33**, 91, 1911.

[2] *Bulletin of the Bureau of Standards*, **2**, 319, 1906.

The second method was to mount the metal studied between brass terminals and put these in a water-cooled brass vessel with windows for observing the temperature. The vessel was pumped out with a Gaede pump and calcium heated[1] inside in order to remove the last trace of gas. This vessel was 12 cm in internal diameter and 18 cm high, with windows 2.5 cm in diameter. The lower terminal was connected to the outside with a packed joint which allowed the filament or wedge to be kept straight. After the pump had been run for 24 hours the tantalum would continue for some time at constant temperature, if the current was kept constant; and the drop in voltage across the filament would also remain constant. This was taken to indicate good working condition. The tantalum filaments were rolled from strips obtained from Siemens and Halske, while the tungsten filaments were of two kinds. The first were from a series tungsten lamp from the General Electric Company, and the second were made from ductile tungsten

TABLE V

Black-Body Melting-Point of Tungsten............ $\lambda = 0.658$

Filament	2827° C.
Strip	2778
	2793
	2814
	2814
Lamp over furnace	2791
Strip	2791
	2770
	2770
	2791
	2820
	2800
Mean	2797° C.

obtained from the same company. All the filaments used were about 3 cm long, the flat ones from 0.7 to 2.0 mm wide and from 0.05 to 0.3 mm thick, and the filaments from the tungsten lamp were 0.3 mm in diameter. The flat filaments were made a little narrower at the middle so that they would heat more at this point.

[1] Soddy, *Proceedings Royal Society*, A **78**, 429, 1906.

In Table V are given results for tungsten, and for tantalum in Table VI.

Taking the mean of the values for the black-body melting-point of tungsten as given in Table V, and extrapolating the curve showing the relation between the true and black-body temperature to this black-body temperature, we obtained 3030° C. as the true melting-point of tungsten. This is thought to be too high, as the surface of the tungsten used in the work with the wedge changed as a result of being run so long at the high temperatures.

TABLE VI

BLACK-BODY MELTING-POINT OF TANTALUM............ $\lambda=0.658$

(Figures in parentheses following values indicate weights given)

Strip	2486 (1)
	2517 (2)
	2530 (3)
	2492 (1)
	2515 (2)
	2495 (1)
	2472 (½)
Mean	2511° C.

MELTING-POINT OF TANTALUM AS OBSERVED FROM WEDGE

	2795° C.
	2786
	2805
	2790 (2)
	2785
	2830
	2805
Mean	2798° C.

DISCUSSION OF RESULTS

The results for the melting-point of tungsten as obtained from the graphite tube furnace are seen to have quite a wide variation. This for the most part is thought to be due to the temperature of the furnace increasing in some cases too rapidly because of varying voltage. In this case the disk would not immediately assume the temperature of the walls of the heater tube. The variation of the observed black-body melting-point of both tantalum and tungsten

may be due to the pyrometer not being sighted at the exact point on the strip at which melting occurred. The mean of the values given for both the black-body temperature and the true temperature are thought to be accurate to about 1 per cent.

TABLE VII

VALUES FOR THE MELTING-POINT OF TUNGSTEN

Observer	Date	Method	Value Accepted for Melting-Point of *Pt.*	Trials	Value	Average Departure from Mean
Waidner and Burgess	1907	Extrapolation . . .	1753° C.	8	3080° C.	28° C.
Pirani......	1910	Extrapolation . . .	1745	..	3250	..
Ruff........	1907	Carbon-tube furnace	1745-55	..	2650	33
Wartenberg..	1910	Black-body melting-point and reflecting power	1745	7	2930	30
This work...	1911	Furnace	1755	13	2974	27
This work...	1911	Observations on wedge	1755	1	2975	..
This work...	1911	Black-body melting-point and wedge	1755	11	3030	16

VALUES FOR THE MELTING-POINT OF TANTALUM

Observer	Date	Method	Value Accepted for Melting-Point of *Pt.*	Trials	Value	Average Departure from Mean
Waidner and Burgess	1907	Extrapolation . . .	1753	5	2910	..
Pirani......	1910	Extrapolation . . .	1745	..	3000	..
Pirani......	1911	Black-body melting-point and reflecting power	(*)	14	2700	30
This work...	1911	Wedge..........	1755	8	2798	13

*This value has been reduced to a scale with the melting-point of palladium 1549° C. in place of 1575° C. and $c_2=14{,}500$ in place of 14,200.

The results for the true and black-body melting-point of tungsten are seen to be about 100° C. lower than the corresponding temperature as found by Waidner and Burgess (*loc. cit.*). As was pointed out above, their work might have an error of that amount. The value for the melting-point of tungsten as found by v. Pirani (*loc. cit.*) is about 300° C. higher than the results given above. As was shown above, his results are in question due to possible errors. The results for the black-body melting-point of tungsten as given by von Wartenberg (*loc. cit.*) check well with the values given

in this work, the difference in the final values being about that due to the different scales used. This is a satisfactory agreement, as he actually measured the black-body temperature.

As for the results on tantalum, they do not agree with other determinations of this point. Unless the metal changes in some way at the higher temperatures, it is hard to see why there should be this much difference between the several determinations. In Table VII is given a summary of all the work on these two metals, with values found and the scale used.

SUMMARY

The melting-point of tungsten has been found by two methods which are seen to agree within about 1 per cent, the value obtained by measuring the point directly in a black-body furnace being 2974° C., while that obtained from the relation between the true and black-body temperature as measured from the wedge is 3030° C.

The melting-point of tantalum was determined from direct observations upon a melting wedge of the metal, giving a value of 2798° C.

In conclusion I wish to express my thanks to Professor Mendenhall for his many valuable suggestions and assistance in all parts requiring two observers.

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